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DEVELOPING ENGINEERING DESIGN CORE COMPETENCES THROUGH ANALYSIS OF INDUSTRIAL PRODUCTS

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ABSTRACT

Most product development work carried out in industrial practice is characterised by being incremental, i.e. the industrial company has had a product in production and on the market for some time, and now time has come to design a new and upgraded variant. This type of redesign project requires that the engineering designers have core design competences to carry through an analysis of the existing product encompassing both a user-oriented side and a technical side, as well as to synthesise solution proposals for the new and upgraded product. The authors of this paper see an educational challenge in staging a course module, in which students develop knowledge, understanding and skills, which will prepare them for being able to participate in and contribute to redesign projects in industrial practice. In the course module Product Analysis and Redesign that has run for 8 years we have developed and refined a product analysis method and a staging of it, which seems to be very productive. Product Analysis and Redesign is a first year course module of the bachelor education Design & Innovation at the Technical University of Denmark. In this paper we will present our product analysis method and we will reflect on the empirical material from the students' application of the method as a means to verify it. We will discuss the product analysis method and the course module in relation to the CDIO-approach, and we conclude that the product analysis method is an important contribution to the conceive stage, is relevant for many engineering disciplines, and can be applied in engineering education from first year.

KEYWORDS

Product analysis method, redesign, industrial products, conceive, competences.

1 INTRODUCTION

Many product development projects in industrial practice are directed towards designing a new and upgraded variant of an existing product, which has been on the market for some time. These redesign projects require that the engineering designers understand needs and requirements from users and other stakeholders, and know how the existing product functions and how it is manufactured. Thus, for an engineering designer to be able to

contribute to a redesign project, he/she must have competences to carry through a composite analysis of the existing product and how it is used and valued by the users. The analysis has to encompass both a user-oriented and a technical perspective, and the analysis result has to provide the engineering designers with an understanding of the product's *raison d'être* as well as attractive and realistic improvement potentials.

Our educational challenge is to stage a course module, in which the students build competences to participate in and contribute to redesign projects. In the course module Product Analysis and Redesign that has run for 8 years we have developed and refined a product analysis method and a staging of it, which seems to be very productive in building the students' competences.

Since the course module Product Analysis and Redesign was developed in year 2002 it predates the CDIO-approach [1]. However, with respect to 'conceive' we see some similar formulations. Crawley et al. [1, p. 8] define, "*The Conceive stage includes defining customer needs; considering technology, enterprise strategy, and regulations; and developing conceptual, technical, and business plans.*", which overlaps with our formulation from the previous page: "These redesign projects require that the engineering designers understand needs and requirements from users and other stakeholders, and know how the existing product functions and how it is manufactured." Unfortunately, in [1] only a few lines are given to unfold the definition of conceive, and among the CDIO standards [1, p. 35] we do not find a standard regarding conceive. We believe that the course module Product Analysis and Redesign contains interesting and relevant elements with respect to 'conceive', and we hope the CDIO community will find inspiration towards formulating a Conceive standard and/or a set of guidelines.

In this paper we will present our product analysis method and its staging within the course module Product Analysis and Redesign. The product analysis method has been applied for 8 years on 45 industrial products and close to 500 students and we will use empirical material in order to verify the method.

The structure of the paper is the following: In the next section we will briefly describe the course module Product Analysis and Redesign in order to outline the educational context of the product analysis method. In section 3 we will present our product analysis method and its staging within the course module. Then in section 4 we will reflect on the empirical material from the students' application of the method as a means to verify the method. In section 5 we will discuss the product analysis method and the course module in relation to the CDIO-approach and we conclude.

2 THE COURSE MODULE PRODUCT ANALYSIS AND REDESIGN

In this section we will briefly describe the course module Product Analysis and Redesign since it constitutes the educational context of the product analysis method. Product Analysis and Redesign is a first year course module of the bachelor education Design & Innovation at the Technical University of Denmark. The purpose of the course module is to build the students' competences, so a student will be able to participate in and contribute to redesign projects in industrial practice in his/her professional career.

Let us imagine a product development project in an industrial company where the project goal is to design a new and upgraded variant of an existing product, which have been at the market for some time. The company has set up a suitable design team with respect to size and disciplines to carry through the project. For a successful redesign project it is required that the team members not only can synthesise a new and different technical solution. It is paramount that the design team members understand needs and expectations from users and other stakeholders, in order to increase the probability that the new and different solution

results in a product, which will be seen as attractive and upgraded by users and potential customers. Thus, for the engineers to be able to contribute to the redesign project they have to have the following four engineering design core competences:

1. A *mindset* so they can identify values seen in the users' perspective.
2. To be able *to conduct research* where they analyse an existing product and explore how users use and perceive the product in order to identify improvement potentials.
3. To be able *to synthesise* solution proposals using creative and systematic methods.
4. To be able *to document* the research and the synthesis results.

We have developed the course module Product Analysis and Redesign based on our understanding of redesign projects in industrial practice as it is described in the previous paragraph. The three central ideas in the course module design are:

1. The course module shall develop the students' knowledge, understanding, and skills toward the four engineering design core competences.
2. The learning activities, learning objectives, and assessment methods have to be aligned, [2].
3. Each student design team shall have an existing industrial product to analyse and redesign.

To the authors' knowledge there does not exist a textbook on redesign. We are aware of a textbook in reverse engineering [3], but this book has a too narrow technical focus for our purpose. However, with respect to teaching synthesis (core competence no. 3) there exist several textbooks on engineering and product design, [4], [5], [6], and [7]. We have chosen to use Cross' textbook [4] in the course module for two reasons: Cross' description of the design process is in line with our understanding, and the amount and undergraduate level of text is suitable. For the course module to fulfil its purpose we have to supplement Cross' textbook with a product analysis method and with a way to document the research and synthesis. The product analysis method shall make the students able to analyse an existing product with respect to function and manufacture and to explore how users use and perceive the product in order to identify improvement potentials in the users' perspective. The method is described in the next section.

As a means to document the research and synthesis we teach the worksheet technique. The worksheet technique has been used in the teaching in engineering design at our university for at least 30 years. We do not know an original reference to this technique, but Hansen [8, p. 57] describes the worksheet technique: *"A work sheet is written in a fixed layout with a heading containing topic, name and date. A work sheet forms an information entity, which clarifies a certain topic or aspect, e.g. requirements, setting up solution alternatives, consideration with respect to life phase, or evaluation and decision. A work sheet may be from one page up to 20 pages. Several techniques are used in the work sheet, e.g. writing notes, sketching and drawing, diagrams from experiments, and photos. ... Thus, work sheets contain the designer's considerations and arguments during design work."* Figure 1 shows a page from a work sheet on the design of a landing gear of an ultra light air plane.

The course content consists of Cross' textbook on product design, the product analysis method to understand both the user-oriented and the technical side of a product, and the worksheet technique to make simultaneous documentation of the student design team's considerations, clarifications, arguments, and decisions. The course content is applied on an existing industrial product, which a student design team has to analyse and redesign. Aligned with these learning activities we have defines the following set of learning objectives of the course module [10]:

Nr.: 14-1	Kapitel: Understel
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af 5	

28/11 2011

Ved 3 hjul har man en god sikkerhed for at alle hjul er i kontakt med underlaget næsten uanset dets belæsthed. Dette kan man ikke være sikker på ved understel med flere hjul, hvis underlaget er ujævnt.

Den ekstra vægt fra det ekstra hjul og ben og dets styring retfærdiggør tilsvarende, ikke den ekstra sikkerhed mod væltning o.lign.

Ved optrækkeligt understel giver det ekstra hjul og ben problemer med plads.

① bruges implicit med de andre i højere eller lavere grad. Uden yderligere fordybelse i denne problematik vil vi vælge ② da denne er langt lettere at producere, servicere og vejer mindre end ① og ③.

Næsehjulet anbringes på kroppen af symmetrienssyn og de styringen til næsehjulet kan laves simpel.

Hovedhjulene kan fastgøres til krop eller vinge.

	①	②	③
① EROP			
② VINGE			
③ TIPPER			

	Fordele	Ulemper
①	* Kan bruges uanset vingeplacering	* Pådrager problemer hvis optrækkeligt understel
②	* "Gør flyet lettere" til optrækkeligt understel	* Flyet er svært håndterbart ved adskillelse for transport hvis delflader er indfor (anbringelsestilstand) for understel
③		* Kan bruges ved lavt indfald vinge/de fly

Alternativt: Fordele! Ulemper!

Figure 1. A page from a work sheet. Four alternative ideas for a landing gear of an ultra light air plane are considered, [9]

"A student who has met the objectives will be able to:

- describe a product's structure, mode of action and embodiment (mode of action analysis).
- describe a product's manufacturing and assembly (manufacturing analysis).
- identify the socio-technical context, which the product is part of, and clarify the assignment of meaning in use through interview with and observation of different actors (user analysis).
- interpret the results from the three analyses into a number of improvement aspects and on this basis formulate requirements and criteria for a specific redesign task.
- create solutions alternatives for a specific new embodiment using a combination of systematic and creative techniques.
- select and detail solutions considering functionality, manufacturing and use.
- make a technical assessment of the merit of the solution alternatives with respect to requirements and criteria.
- argue for value in use based on the change in the socio-technical context.
- make work sheets to document observations, considerations, solutions, experiments and decisions in the work with analysis and synthesis.
- read and discuss the work sheets made by others as a mean to share collected knowledge in the analytical work and clarifications during synthesis work.
- redesign a product based on the relevant analyses and the proposed alternative solutions.
- reflect on the quality of the redesign activity and own contribution."

The relations between learning objectives, learning activities, and engineering design core competences are intended to be the following. Learning objectives A, B, and C constitute the requirements of the product analysis method on the one side, and contribute to building core competence 2: To be able to conduct research on the other. Learning objectives C, D, and H contribute to building core competence 1: A mindset to identify values in the users' perspective. The learning objectives E, F, G, and K are aligned with Cross' textbook on the

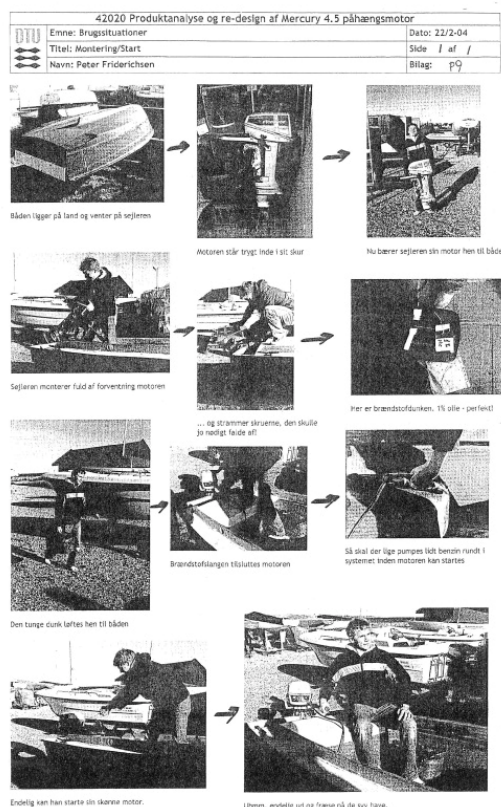
one side and contribute to building core competence 3: To be able *to synthesise* on the other. Learning objectives I and J are aligned with the worksheet technique on the one side and contribute to core competence 4: To be able *to document* on the other. The last learning objective L regarding the student's reflection on the redesign activity and his/her own contribution is intended to make the student aware of his/her personal development of knowledge, understanding, and skills by participating in the course module.

3 THE PRODUCT ANALYSIS METHOD

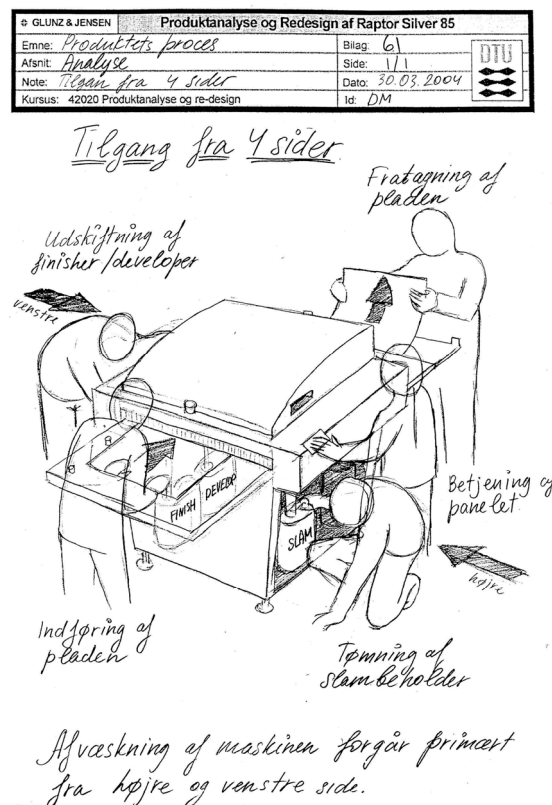
In this section we will describe our product analysis method. Firstly, we describe the theoretical basis of the model, and thereafter three important elements in the staging of the method in the course module Product Analysis and Redesign.

The product analysis method

The educational goal with the product analysis method is to give the students an understanding of both a user-oriented and a technical side of a product. The user-oriented side is related to how users use and perceive the product, and the technical side is related to how the product functions and how it is manufactured. Thus, the students have to develop a mindset that a product is not a technical artefact having value in itself. Value is to be found in the users' reaction when they use the product, i.e. value of the product has to be seen in the user perspective.



(a)



(b)

Figure 2. Two work sheets on use processes. (a): Shows the operations involved in mounting an outboard motor on a boat, [15]. (b): Shows that the developer for large printing films has to be accessed from all 4 sides, [16].

The fundamental idea in our product analysis is based on the domain theory [11], [12], which states that a product to be designed can be seen by the engineering designer in three

domains. Firstly, the *activity domain* where the engineering designer focuses on the purposeful transformation when using the product, e.g. when a person uses a tumble dryer to dry clothes, the clothes are transformed from being wet to being dry. Secondly, the *organ domain* where the engineering designer focuses on the product's active elements (the organs) which create physical effects, and their mode of action. In a tumble dryer we find e.g. a revolving drum, a burner, and a blower. The revolving drum is an organ which makes the clothes tumble, and the burner and blower are organs, which create a flow of hot air to make the water evaporate from the wet clothes. Thirdly, the *part domain* where the engineering designer focuses on the allocation of the organs into parts, which can be produced and assembled.

In accordance with the domain theory and the goal to understand both the user-oriented and the technical side of a product we have developed a *product analysis method*, which encompasses three analysis dimensions:

1. *Use process analysis*: To understand users and other relevant stakeholders, e.g. maintenance, repairing and disposal.
2. *Mode of action analysis*: To identify the product's organs and their mode of action.
3. *Manufacturing analysis*: To analyse the production of single components (parts) and their assembly into a complete product.

The *use process analysis* is based on a socio-technical approach [13], [14]. The student design team has to identify a relevant actor-network related to the existing product and collect information from the actors. Actors can be human, e.g. users and maintenance persons, and information collection can be carried out by observing actors in action or interviews. Actors can be non-human, e.g. legislative requirements with respect to the product and its use, maintenance, or disposal, and the information collection is carried out by discourse analysis of documents. Figure 2 shows two work sheets on use processes.

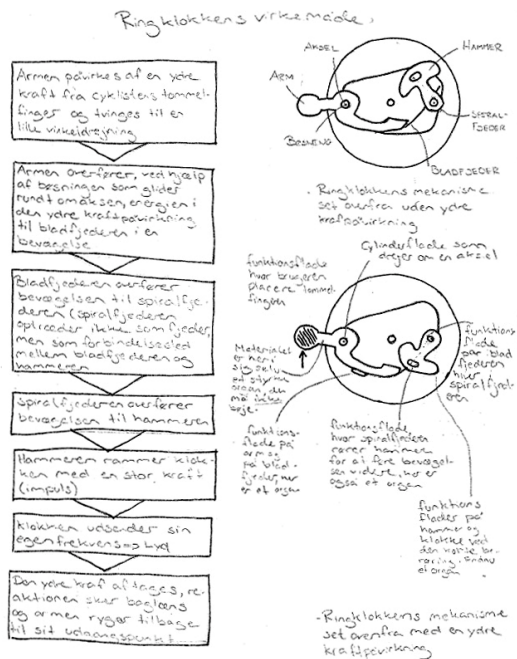
The *mode of action analysis* is carried out in the workshop. The student design team takes the product apart (product dissection), identify the organs and their mode of action. Let us imagine a student design team taking a tumble dryer apart. The team has identified an electrical heater as an organ to heat air, and a blower as an organ to create a flow of air. However, the team realises that the heated air flow has to be directed through the revolving drum, and they identify the airway as an organ. The airway consists of sheet metal plates to direct the air flow and holes in the revolving drum to lead the air through the tumbling clothes. Figure 3 shows two work sheets regarding mode of action of a Christiania bike.

The *manufacturing analysis* is carried out in the workshop. While the student design team disassembles the product they identify single components and reason about the assembly sequence. For each component the type of material and manufacturing process is to be identified. An important element is the identification of *signs* given by the component, e.g. feeling the weight and temperature when holding the component in the hand to identify the type of material, and looking for signs from the production process, e.g. cutting marks from a milling machine or angles from a sheet metal bending. Figure 4 shows two work sheets of manufacturing analysis of a concrete mixer.

For each of the three analysis dimensions we have formulated some inspiration questions to initiate the product analysis. The questions are generic in the sense they are relevant to many industrial products. As a student design team works on the product analysis related to their given product and begin to provide answers to the inspiration questions, new specific questions emerge to be answered. Thus, gradually the students' insight and understanding of the user-oriented as well as the technical side of the product grows. Our product analysis method is not characterised by carrying through a given sequence of method steps, which leads to a required result. The method is characterised by a spiral movement through the three analyses, use process-, mode of action-, and manufacturing analysis. In this spiral

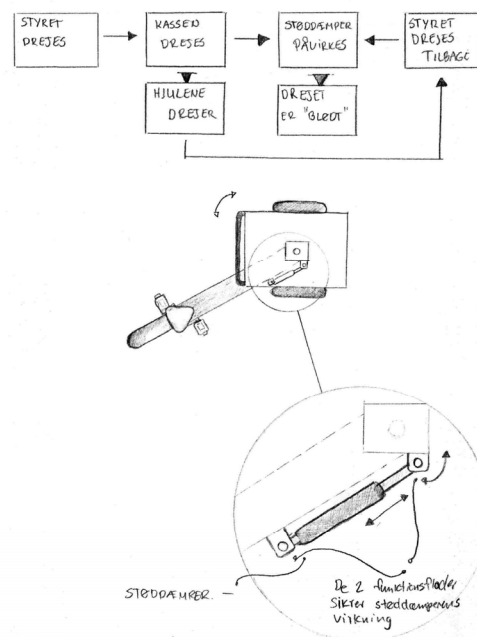
movement the student design team builds an understanding of “what is good?” and “what could be better?” in the users’ perspectives as well as insight into the product’s mode of action and how it is manufactured. We apply two stopping criteria for the product analysis. The analysis has to be carried through within a given time period, and the analysis has to result in the student design team’s formulation of three improvement potentials.

DTU 42020 - Hold 1 Christiania-bike		
Navn: ICH	Dato: 05-04-2005	
Emne: Ringklokke	Bilag nr.: 1	
Note: Virkemåde	Side: 1 / 2	



(a)

DTU 42020 - Hold 1 Christiania-bike		
Navn: BMH	Dato: 05-04-2005	
Emne: Dæmper	Bilag nr.: 3	
Note: Virkemåde	Side: 1 / 1	



(b)

Figure 3. Two work sheets regarding mode of action of a Christiania bike. (a): Shows the mode of action of the of the bell using 2 drawings and a flow chart. (b): Shows the damping mechanism to obtain smooth turn, [17].

The staging of the product analysis

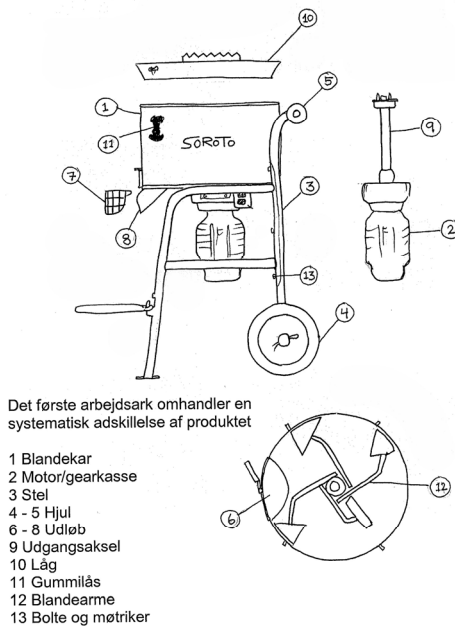
There are three important elements in the staging of the product analysis method in the course module Product Analysis and Redesign. Firstly, we use existing industrial products, which the student design teams have to redesign. To each student design team is assigned *a product and a company contact person*. The company contact person is available to answer questions and to help the team to identify and make contact to users and other relevant stakeholders, e.g. maintenance persons. This is beneficial especially in the initial stage of the product analysis, but the company contact persons also has a positive effect on the students’ motivation, because he/she is looking forward to see the student design team’s solution proposals for an improved product

Secondly, in order to make an extensive and detailed product analysis within the time frame given we let the students work in rather large design teams. Each student design team has 10 members. With careful supervision regarding task delegation and knowledge sharing a 10 person’s student design team is able to carry through an extensive and detailed product analysis. Whereas a large student design team is suitable for the product analysis, this is not good for the redesign task. Since the students are first year undergraduates, their technical discipline knowledge is modest, which means the redesign task must not be complex. And it is overkill to ask a 10 person’s student design team to carry through a noncomplex redesign

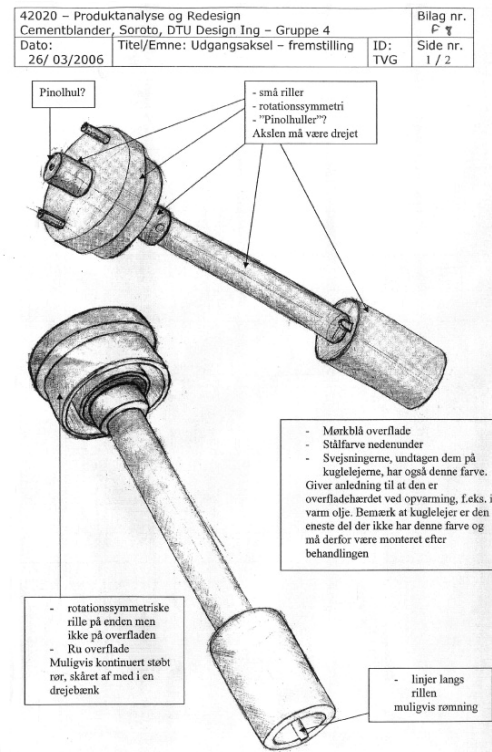
task. We solve the problem in the following way. The large student design team has to carry through their product analysis and identify and formulate at least three improvement potentials, and thereby establish the basis for at least three redesign tasks. Thereafter, the students distribute themselves into two 5 person's student redesign teams, and each redesign team selects an improvement potential to pursue. We obtain redesign teams of a suitable size, and the company contact person receives solution proposals for an improved product with respect to two different improvement potentials.

Fremstilling og montage

Neden for ses rækkefølgen, som arbejdsbladene er ordnet i. Nummereringen på denne side henviser kun til denne illustration



(a)



(b)

Figure 4. Two work sheets of manufacturing analysis of a concrete mixer. (a): Shows the concrete mixer's components. (b): Shows the analysis of the shaft's materials and manufacturing using signs like machining marks, colour and weight, [18].

Thirdly, a general idea in the Design & Innovation education is that the students must be able to communicate graphically during design. Both when they are working individually, and in meetings, workshops, brainstorm, etc. We therefore require that they train their hand drawing skills, and for the same reason we postpone the training in computer drawing until the second year. Hand drawing furthermore has the advantage – especially compared to photo – that only the relevant details are presented. The work sheet in figure 4 (b) is a good example of this. The overview of the concrete mixer is much clearer in this type of drawing that only display the product components in focus. A photo would show a lot of other unnecessary information that would blur the communication. However, photos are often beneficial when documenting a sequence of user operations. The work sheet in figure 2 (a) is an example of this. The photos give a very realistic understanding of the user's perspective when mounting the outboard motor.

We see this section contributing with two elements towards formulating the content of Conceive guidelines. Firstly, a product analysis method which has a theoretical basis and encompasses three dimensions: a use process analysis, a mode of action analysis and a manufacturing analysis. Secondly, a mindset element to identify values seen in the users'

perspective, where the key point is that “what is good?” and “what can be better?” are not determined or decided by the student design team.

With reference to the condensed CDIO syllabus [1, p. 55] the product analysis method and its staging proposes some means for a teacher to consider. To develop the students’ ‘professional skills and attitudes’ (syllabus element 2.5) the product analysis method and its staging offers both a rather large student design team and access to company contact person and users. With respect to syllabus element 3.2 ‘Communication’ work sheets with writing, sketching, various types of drawings and photos is an important technique.

4 RESULTS: VERIFICATION OF THE PRODUCT ANALYSIS METHOD

In this section we will collect evidence to verify the product analysis method. Firstly, we describe our empirical material and thereafter we will reflect on the material focusing on the following questions:

- Lessons learned by the teachers: what went well and where is room for improvement?
- Has the mindset element been understood?
- Have all three elements in the analysis, viz. use process, mode of action and manufacturing been considered properly?
- Does the final redesigned product represent significant improvements which are valued by the industrial client?
- Do the students use the methodology later on in their study?

Finding products is a returning pleasure and challenge, since we every year has to find 6 new products and preferably also industrial partners. The procedure is that we brainstorm on possible new products. Industrial partners are then contacted. There are 4 basic criteria that the products have to meet:

1. There should be a plurality of relevant human actors, e.g. users, maintenance personnel, and cleaning people.
2. The products must have a manageable technical complexity that can be handled in the mode of action analysis.
3. Reversible disassembly should be possible and the products must represent a reasonable amount of different materials and manufacturing processes. It is an advantage if there is a production facility for the students to visit.
4. The products have to be of a reasonable size, so they can be handled in the workshop.

In the years 2003 until 2010 we have worked with a total of 45 products. There were 20 consumer products and 25 professional products. Thus, 45 student design teams carried through a product analysis, and then split up into the smaller student redesign teams. In total 92 student redesign teams have redesigned the products.

In order to illustrate the range of products we have used in the course module, we have selected 9 products as shown in figure 5. There are 4 consumer and 5 professional products:

1. The Christiania bike is a carrier bicycle that primarily is used by families with small children as an alternative to a car in urban areas. The bicycle is also used professionally e.g. for mail delivery, but the professional users constitute a very small market segment compared to the consumer market.
2. The food mixer is primarily used for mixing bread dough and is targeted towards the upper end of the consumer market and the lower end of the professional market.
3. The electrical stove is an ordinary household kitchen element with 4 cooking plates and an oven.
4. The train seat and table are used in the Danish intercity trains. As the students are regularly train passengers they know the use of seat and table very well. Therefore we classify the train seat and table as a consumer product.

5. The oil sampling box kit is used by the inspection authorities to take samples of oil spills at sea in order to collect legal evidence.
6. The unit for parcel handling is used when loading and unloading parcels in freight air planes.
7. The tilting kettle is a large pot for preparing food in professional kitchens like cooking potatoes or making stews.
8. The developer is used for processing large printing films used in the printing industry.
9. The concrete mixer is used by masons for preparing the mortar or the light concrete.



Figure 5. Examples of products used in the course module. The first four are consumer products and the rest are professional products: 1: Christiania bicycle, 2: Food mixer, 3: Stove, 4: Train seat and table, 5: Oil sampling box kit, 6: Parcel handling in aircrafts, 7: Tilting kettle, 8: Developer for large printing films, and 9: Concrete mixer.

Lessons learned by the teachers

Being three persons in the teaching group it has been natural regularly to reflect on the progress within the course module. This is done both informally and more formally when we meet for the brainstorm and after each of the course module milestones.

A first lesson learned is the apparent difference between the way students handle professional and consumer products. We have experienced that in general professional products are better suited than consumer products in the product analysis. The statistics in table 1 qualifies our experience. We have classified the 45 products that have been analyzed and redesigned so far in the course module as either professional or consumer products, depending on whether the products are targeted towards professional users or the customer market. There were 42 student redesign teams working with consumer products and 50 student redesign teams having professional products. When calculating the average of grades of all students there is a difference of about one grade between students working with the two types of products. For students working with consumer products the average grade is 7.9 while students working with professional products got 8.9, see table 1. This is a remarkable difference and confirms our experience. However, we do not conclude that consumer products should not be used in this type of course module. Instead our message is that one should be aware of the problem and accordingly instruct the students to avoid it.

Table 1.
Average grades for student teams working with consumer or professional products. The grading scale goes from -3 to 12, where -3 and 0 are failing, 2 is just passed, and 12 is excellent.

	Number of student design team (10 person's groups)	Number of student redesign teams (5 person's groups)	Average grade
Consumer products	20	42	7.9
Professional products	25	50	8.9

A second lesson learned concerns the number of persons in the student design teams. In the first year we only had 4 products which with 60 students gave 15 persons in each student design team. We believed that the large team size would force the students to organize themselves better. However, the experience was that this was not fruitful, e.g. at one occasion the members in one student design team could not agree, which resulted in a conflict. Thus, we decided a student design team size of 10 persons during the product analysis.

A third lesson learned concerns "product fixation", i.e. seeing and understanding not only mode of action and manufacturing but also users and use process from the product's perspective. The first time the course module was run we experienced some student design teams developing a product fixation. We identified the cause of this unfavourable product fixation in the fact that these student design teams initiated their product analysis in the workshop taking the product apart. In year 2004 we introduced a rule saying is it not allowed to take the product apart in the first three weeks of the product analysis. This rule forces the student design teams to work outside-in, and since the introduction of the rule we have not experienced whole student design teams developing product fixation.

Understanding the mindset

A central objective in the course module is to make sure that the students develop the mindset that a product is not a technical artefact having value in itself, but that value is found in the users' reaction when they use the product. To evaluate if this objective has been met we can look at the proposed improvement potentials and the underlying argumentation which is the outcome of the analysis. We have looked at the 9 products shown in figure 5. The 9 products were selected as examples of both consumer and professional products. Table 2 describes the improvement potentials for the 9 products proposed by the student design

teams, and our comments on their relevance. We determine the relevance of a proposed improvement potential by judging whether a product which is successfully redesigned with respect to the proposed improvement potential will be valued as better in the users' perspective. The table illustrates our assumption that it can be problematic to use consumer products for teaching product analysis and redesign since students know the products in advance and are therefore less eager in consulting a range of relevant users. They think that they already know many of the answers themselves from their own daily practices.

Table 2
Improvement areas for the 9 products shown in figure 5 and comment on relevance

	Type of product	No. of improvement areas proposed by the student design teams	Teachers' comments on relevance
1. Christiania bike	Consumer	3 areas: Theft protection, performance, accessories	Two very relevant areas
2. Food mixer	Consumer	3 areas: Additional functions, interface/ security and appearance/ mobility	The areas have only limited relevance
3. Stove	Consumer	3 areas: Cleaning, appearance and efficiency	The areas have only limited relevance
4. Train seat and table	Consumer	7 areas: Cleaning, adjustment, comfort (3 types), luggage, newspapers	The areas are relevant but unclearly described
5. Oil sampling box kit	Professional	6 areas: Usability (transparency, sealing, overview), content (oil container, sampler, extra elements)	All areas are very relevant
6. Parcel handling in aircrafts	Professional	4 areas: Ergonomics, maintenance, efficiency, inviting use	Two of the areas are very relevant
7. Tilting kettle	Professional	2 areas: The cooking process (8 topics) and cleaning (5 topics)	The two areas are very relevant
8. Developer for printing films	Professional	6 areas: Access, cleaning, four problematic components, automation, ease of use, change of context	Three areas are relevant
9. Concrete mixer	Professional	4 areas: Transport, safety, cleaning and appearance	Three areas are very relevant

The students proposed a varying number of improvement potentials for the 9 products ranging from 2 to 7. The analysis of the professional products more often resulted in good and relevant improvement potentials, which are in good agreement with our assumption that the students make a better use process analysis for products of which they have no personal experience with.

An example of how a good use process analysis resulted in very relevant improvement potentials is the film developer (no. 8 in figure 5). It was easy to recognize poorly functioning technical details like a lid that is difficult to close. But a significant improvement potential was uncovered when the working and cleaning procedures was studied in collaboration with operators. Here the students noticed that it was necessary to have access to all 4 sides of the machine, and the workers therefore had to move around the machine in order to perform the different activities, see figure 2 (b). This made the operation of the machine less efficient and limited the placement of the machine to positions away from the wall. A relevant improvement potential was therefore to investigate if the machine could be redesigned so it could be operated from one or two sides only.

Another example illustrates how a poor use process analysis leads to improvement potentials with limited relevance. All the students were familiar with food mixers from their own kitchens, and their own private opinions heavily influenced which problems they identified. The existing food mixer (no. 2 in figure 5) was quite large and targeted consumers that were willing to buy the relatively expensive mixer. The student design team proposed to reduce the size and appearance (give it a more fancy look), but they could not document that the user group (which is very different from students who have limited budgets and space in their homes) would value such improvements. The product reminded too much of artefacts from the students everyday life and they could not abstract from their own opinions, which in this case highly biased the use process analysis. The student design team working with the stove (no. 3 in figure 5) had similar problems, since all students were using one at home, and therefore were reluctant to find representative users.

The three analyses

Another objective in the course module is to ensure that the students build knowledge, understanding and skills within all three product analysis dimensions, viz. use process-, mode of action-, and manufacturing analysis. All student design teams conduct the three analyses, but the quality naturally varies. In the previous section we discussed one of the pitfalls for the use process analyses. We will here look at the two other analyses.

Our approach is to let the product motivate and direct which detailed analyses that the students will carry out. The mode of action analysis can be approached in a number of ways. A traditional one would be to describe the functions and sub-functions in the product and what means that are used to make this happen using a function-means tree. We use the 'organ' notion to document the means as described earlier in the paper. To investigate the dynamics of a product we have good success in using a technique that can be called 'a medium's passage through the product'. This can be illustrated by the concrete mixer (no. 9 in figure 5) where we can look on how electricity passes through the product. From the power outlet the electricity passes through a cable to a power-switch, further on to a safety switch that detect if the lid is closed and then into the electric motor where a rotary motion is generated. This is an intuitively easy technique to use and gives good insight into especially more complex products.

The manufacturing analysis is supported within the course by theoretical lectures where the different manufacturing processes are explained and students try to operate some of them in the workshop. In general the students make reasonable analyses of how the single components in their products are produced using the earlier described technique, i.e. identification of signs given by the component, where typical marks from the manufacturing process are identified and used to argue for how the part is produced. This is very much a graphical exercise where drawing capabilities are important. Students sketch the single components and preferably also the contours of the tools and dies used to make the components. Insight into assembly will in most cases come from the disassembly of the products done by the student design team. When dismantling the products they have to make notes so they can assemble the product again correctly. A part of the manufacturing analysis that often represent difficulties for the students is the account for where changes to the product is easy or difficult to make due to earlier investments in tooling or preferred materials and mode of production. The reason is that this requires a better insight into how industrial production takes place within a company. To supply the students with a minimum of this type of insight an excursion to one or two producing companies is part of the course curriculum.

Improved products

The quality of the final redesigned products should primarily be judged by the knowledge, understanding and skills that the students have acquired by making them. The course module is at first year and students cannot be expected to come up with improvements that will revolutionize the collaborating company. However, in a number of cases the results have been beneficial to the industrial client. At two occasions, the clients liked the outcome so much that they wanted to participate again with another product. After the redesign of a spinning bicycle another student design team was assigned to the redesign of a cross country ski-exercise machine. The redesign of a hospital bed was followed by the redesign of a patient lifting device. The redesign of the spinning bicycle was valued so much by the client, so many of the improvements proposed by the students are now implemented in the new version of the product. The redesign of the industrial tilting kettle to cut down on the large cleaning expenses proposed a radical solution where a large disposable plastic cup was to be used within the tilting kettle resulting in an almost elimination of the cleaning activity. It would furthermore introduce a new significant business model where the company would get a continued sale of plastic cups. The company liked the idea but feared that the conservative customers would not be in favour of the new design. Besides, there were technical challenges about heat transfer that needed to be investigated.

Apart from the concrete products resulting from the redesign there are other outcomes from the students that are valued by the industrial clients. One outcome is the use process analyses. The students have a unique possibility of get close to many users that can be difficult to approach for the industrial clients. Being a curious student opens many doors. Another outcome is the user network that the students can facilitate. The parcel handling within aircrafts is a good example of this. The students participated themselves in the parcel handling in the airport and managed to involve the workers in the design activity – a task that is much more difficult to approach for the employer.

Do the students use the methodology later in their studies?

Our experiences from bachelor projects (6th semester), final year projects (10th semester) and the project oriented course Holistic design (9th semester) are that the vast majority of students have acquired the product analysis method and use it again in their design projects. In particular this include the use process analysis and the product specification techniques, but also synthesis techniques from the other half of the course like morphology and comparison techniques are widely used. The worksheet technique is also widely applied in later student reports.

5 DISCUSSION AND CONCLUSIONS

Based upon the collected evidence from the empirical material we allow ourselves to conclude that the proposed product analysis method is very productive in building the students' knowledge, understanding and skills, and thereby prepare the students to be able to participate in and contribute to redesign projects in industrial practice.

If we discuss the course module Product Analysis and Redesign and our product analysis method in relation to the CDIO approach [1] we observe two interesting items. Firstly, Crawley et al. [1, p. 109] write, *"In the third-year and fourth year, students are given tasks of increased complexity and authenticity. For example, in the third year, they might be asked to redesign existing industrial products in order to improve performance or to decrease environmental load or cost."* Product Analysis and Redesign is a *first year* course module of the bachelor programme Design & Innovation. This paper has shown that it is feasible to give first year students an existing product and a company contact person, and ask the students to carry through a redesign task. It is also very motivating for the students.

Secondly, with respect to the content of the redesign task Crawley et al. [1, p. 109] write, “*At this point, the students are able to make decisions using more situation-adapted strategies, selecting prototypes and simulation methods as needed to support the development process.*” In Product Analysis and Redesign the redesign task has focus on the conceive stage, and the proposed product analysis method encompasses an analysis of both the user side and the technical side of the existing product. The student design team has to analyse users and other relevant stakeholders as well as the product’s mode of action and manufacture in order to identify attractive and realistic improvement potentials.

Although our product analysis method is developed for the Design & Innovation bachelor programme, we believe it is highly relevant in other engineering disciplines. Engineers working in industrial practice, being engineering designers or technical discipline specialists, have to understand that in order to obtain a successful outcome of a redesign project it is paramount to understand needs and expectations of users and other relevant stakeholders. If a technical discipline specialist develops a new technical solution, which is not recognised as being better and upgraded in the users’ or another relevant stakeholder’s perspective, the solution has no value and contribution to the redesign project.

In modern engineering education we have to take socio-technical aspects into account. From a NSF workshop on engineering design in year 2030 [19, p. 1] we find: “*If the US is to capitalize on our research investments in micro-, bio-, info-, nano-technologies, as well as, conventional areas that continually lead to exciting technological advances, we must invest in engineering design tools and techniques in order to convert this research into commercial products.*” The NSF workshop formulates three content recommendations: engineering innovation, social-technical aspects, and design informatics. With respect to the socio-technical aspects, it is stated [19, p. 1]: “*Social-technical aspects: Basic knowledge regarding how humans and social dynamics influence design that involves multiple stakeholders with wide societal roles.*” Thus, from the NSF workshop we observe, that any engineer involved in developing research into commercial products has to have socio-technical competences, irrespective of his/her technical discipline area being “*micro-, bio-, info-, nano-technologies*, as well as, conventional areas.”

In the description of the product analysis method and its staging we have outlined some important elements relevant to formulating Conceive guidelines, and to support the CDIO syllabus. We conclude that the product analysis method proposed and verified in this paper is an important contribution to the conceive stage, is relevant for many engineering disciplines, and can be applied in engineering education from first year.

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